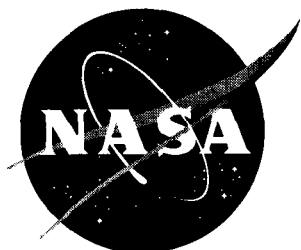


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Concept of Operations for the NASA Weather Accident Prevention (WxAP) Project

Version 2.0

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Lockheed Martin Corporation
Glenn Research Center, Cleveland, Ohio*

September 2003

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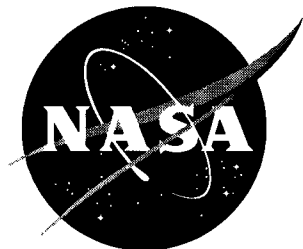
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Nomenclature

ADDS	Aviation Digital Data Service
ADS	Automatic Dependent Surveillance
AGL	above ground level
AIRMETs	Airman's Meteorological Information
AOC	Airline Operations Center
ARC	Ames Research Center
ARTCC	Air Route Traffic Control Center
ASIST	Aviation Safety Investment Strategy Team
ASOS	Automated Surface Observing System
ATC	Air Traffic Control
ATIS	Airport Traffic Information System
AvSP	Aviation Safety Program
AWIN	Aviation Weather Information
AWOS	Automated Weather Observing System
CAT	clear air turbulence
CDM	collaborative decision making
ConOps	Concept of Operations
DFRC	Dryden Flight Research Center
DUATS	Direct User Access Terminal System
EFAS	En-route Flight Advisory Service
ETA	estimated time of arrival
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
FBO	Fixed Base Operator

FISDL	Flight Information Services Datalink
FSS	Flight Service Station
FW	Flight Watch
GA	general aviation
GPS	Global Positioning System
GRC	Glenn Research Center
HF	High Frequency
HIWAS	Hazardous In-flight Weather Advisory Service
IFR	instrument flight rules
ILS	Instrument Landing System
IMC	instrument meteorological conditions
KDFW	airport identifier for Dallas-Fort Worth, Texas
KEKN	airport identifier for Elkins, West Virginia
KIWA	airport identifier for Williams Gateway, Arizona
KJFK	airport identifier for John F. Kennedy, New York
KSFO	airport identifier for San Francisco International, California
LaRC	Langley Research Center
LGW	London Gatwick Airport
LIDAR	Light Detection and Ranging
MEA	minimum en route IFR altitude
METAR	aviation routine weather report
MFD	multi-function display
MVFR	marginal visual flight rules
NAS	National Airspace System
NASA	National Aeronautics and Space Administration

NAV	Navigation
NEXRAD	Next Generation Weather Radar
NOTAM	notices to airmen
NTSB	National Transportation Safety Board
PIREP	Pilot Report
SBGL	airport identifier for Rio de Janeiro International Airport
SIGMET	Significant Meteorological Information
TAF	terminal area forecast
TAMDAR	Tropospheric Airborne Meteorological Data Reporting
TM	Traffic Management
TOCs	transoceanic operations centers
TPAWS	Turbulence Prediction and Warning Systems
VFR	visual flight rules
VOR	VHF Omni-directional radio Range
WINCOMM	Weather Information Communications
WxAP	Weather Accident Prevention

Introduction

This document is created and maintained by the Systems Engineering team and approved by the Weather Accident Prevention (WxAP) Project Management Team. The Weather Accident Prevention Concept of Operations (ConOps) description serves as a decision-making framework for research and technology development planning. It is intended for use by the WxAP project team and other related programs in NASA and the Federal Aviation Administration (FAA) that support aircraft accident reduction initiatives. The concept will outline the project overview for funded program elements such as Aviation Weather Information (AWIN), Weather Information Communications (WINCOMM), and Turbulence Prediction and Warning Systems (TPAWS) that develop the technologies and operating capabilities forming the building blocks for WxAP. Those building blocks include both retrofit of equipment and systems; development of new aircraft and training technologies; and operating infrastructure systems and capabilities.

Background

The Aviation Safety Program (AvSP) is a program of NASA's Aerospace Technology Enterprise. The AvSP specifically addresses the Enterprise's *Enabling Technology Goal* of "reducing the aircraft accident rate by a factor of 5 within 10 years (2007), and by a factor of 10 within 25 years (2022)."

The AvSP is a fully integrated focused NASA program led by NASA Headquarters with lower level management and execution accomplished across all of NASA's aeronautics centers. These include the Langley Research Center (LaRC), the Glenn Research Center (GRC), the Ames Research Center (ARC), and the Dryden Flight Research Center (DFRC). Figure 1 describes the program organization. As previously described, the Weather Accident Prevention (WxAP) Project is organized into three research elements: Aviation Weather Information (AWIN), Weather Information Communications (WINCOMM), and Turbulence Prediction and Warning Systems (TPAWS). The programmatic and technical management for the AWIN element resides at Langley Research Center. The programmatic and technical management for the WINCOMM element resides at Glenn Research Center. The programmatic and technical management for the TPAWS element resides at Dryden Flight Research Center and Langley Research Center (via the TPAWS Deputy Element Manager). Technical support for all elements resides at all three NASA research centers mentioned.

There has been significant research over the past 20 years related to aviation weather hazards such as icing, turbulence, lightning, and wind shear, but weather is still identified as a causal factor in 33% of commercial air carrier accidents and 27% of general aviation (GA) accidents. A continuing area of need has been the collection, processing, distribution, and presentation of timely and accurate weather information to pilots in flight. In the present system, pilots rely primarily on voice communications for in-flight weather updates. Pilots can have difficulty obtaining weather information in a timely manner, assimilating that information into a clear mental picture, and developing a good understanding of changing weather trends. A flight crew that does not have a complete awareness of the weather situation may encounter unexpected adverse weather or may have difficulty making route replanning decisions. In-flight delivery and presentation of graphic weather updates to the crew should facilitate weather situation awareness and collaboration with Airline Operations Centers (AOCs), dispatchers, Flight Service Stations (FSSs), and Air Traffic Control (ATC) for safer, more efficient operations.

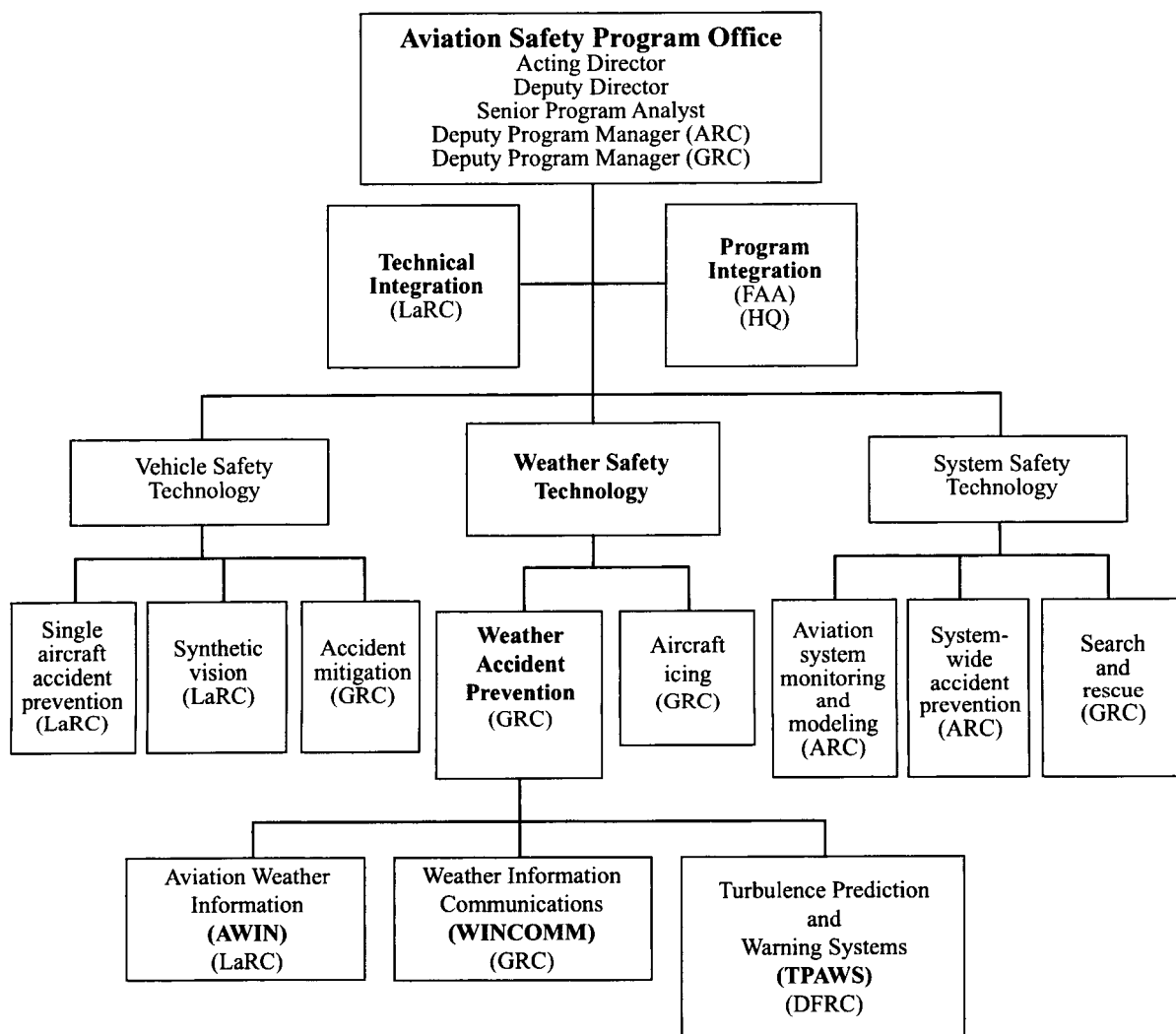


Figure 1. Aviation Safety Program organization showing WxAP and elements.

The U.S. air carrier system is exposed to an inordinately high frequency of turbulence encounters that result in injuries. This exposure is due to several factors, including the convergence of jet streams over North America and the influence of the Caribbean and the Gulf Stream in the Southern and mid-Atlantic regions. There is also a high exposure risk along the western rim of the Pacific where U.S. carriers provide Asian services. In contrast, Western Europe tends to be a region of low turbulence frequency and exposure there is low.

Turbulence data extending from 1980 to 1999 show an average of six accidents and eight injuries per year through 1995. The average then rises suddenly and peaks in the late 1990s at 12 accidents and 16 injuries per year, demonstrating a twofold overall increase. This trend, coupled with the increase of commercial travel predicted for at least the next decade, generates a higher risk level for serious injury or fatality for passengers and cabin crew members. In the future, increasing use of Free Flight routing is likely to decrease the effectiveness of turbulence Pilot Reports (PIREPs) and thereby increase the frequency of turbulence encounters.

During the 16-year period ending in 1999, U.S. air carriers experienced 131 turbulence related accidents with a total of 3 passenger fatalities (one each in 1987, 1990, and 1997). In addition to the 3 fatalities, 83 passengers and 93 flight attendants suffered serious injuries, while 423 passengers and 121 flight attendants suffered minor injuries.

Injuries to flight attendants, as with passengers, are a significant concern. Data from the Federal Aviation Administration (FAA) Accident and Incident Data System, and from one of the major U.S. air carriers, indicate that injuries to flight attendants have a major effect on operating costs and worker injury time. FAA incident data indicate that, for every turbulence accident with serious injuries, three significant incidents without serious injuries are reported to the agency. Data provided by one airline indicate that, for every flight attendant seriously injured in a turbulence accident, 70 flight attendants receive National Transportation Safety Board (NTSB)-defined minor injuries in turbulence incidents, causing an average of more than 11 workdays lost per reported injury. Assuming that the ratios for this large carrier are roughly representative of the entire industry, an average of 10,000 flight attendant workdays have been lost throughout the industry each year in the last 16 years. In the five years from 1995 to 1999, that average has dramatically increased to nearly 15,000 lost workdays per year throughout the industry.

Aviation Safety Program

The NASA Aviation Safety Program is described in the background section of the Weather Accident Prevention (WxAP) Project Plan.

Approximately one third of commercial aviation accidents, and a similar amount of GA accidents, are attributed to adverse weather. The NASA Aviation Safety Investment Strategy Team (ASIST) investigated factors contributing to aviation accidents, including adverse weather, sponsoring four industry- and government-wide workshops to define and prioritize research needs based on technology readiness and potential impact on safety. The ASIST recommendations included a list of priority investment areas for weather accident reduction (table 1). The WxAP Project is addressing 6 of these 12 recommended investment areas as defined in table 2.

Table 1. ASIST Weather Research Priorities

Priority	Investment area
1	Data dissemination
2	Crew/dispatch/ATC monitoring, presentation, and decision aids
3	Icing hazard solutions
4	Training
5	Weather product generation
6	Advanced aviation meteorology
7	Turbulence hazard solutions
8	Advanced technology vision and tactical sensors/systems
9	Near-term tactical sensors/system
10	Strategic wake vortex information
11	Hazard characterization
12	Runway contamination

Table 2. ASIST Investment Areas Being Addressed by WxAP

Priority	Investment area	WxAP
1	Data dissemination	WINCOMM
2	Presentation and decision aids	AWIN
5	Weather product generation	AWIN/TPAWS
6	Advanced aviation meteorology	AWIN
7	Turbulence hazard solutions	TPAWS
9	Near-term tactical sensor/system	TPAWS

Weather Accident Prevention Project

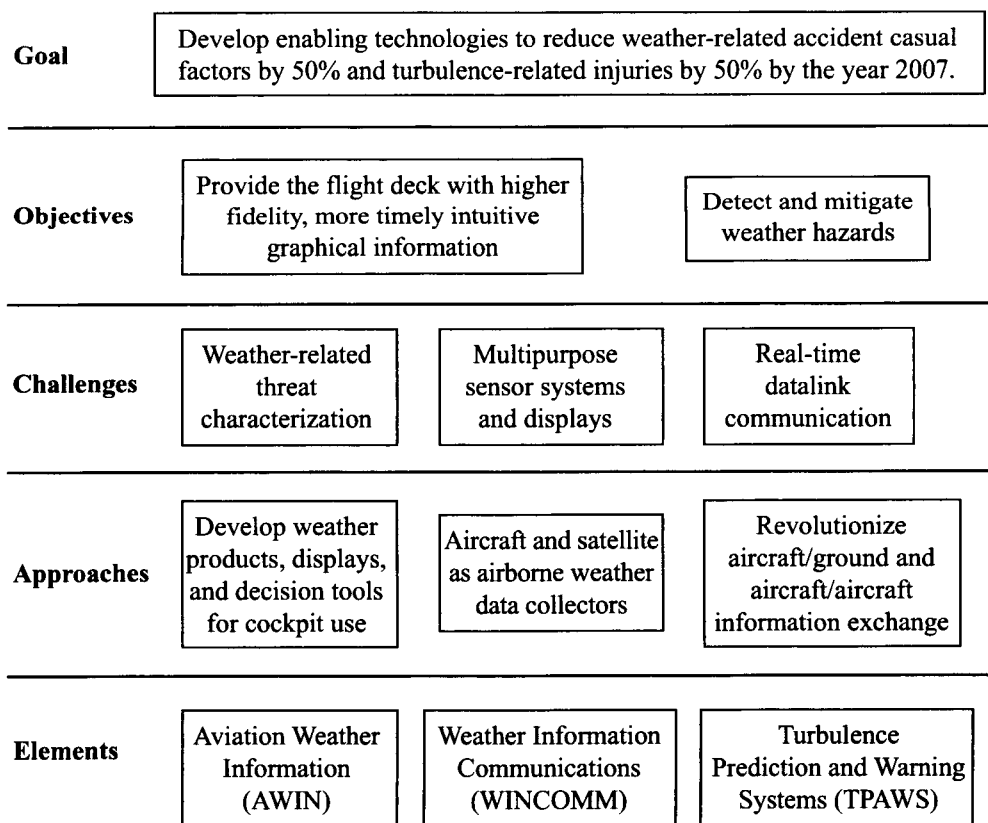


Figure 2. WxAP summary chart.

WxAP Project Overview

The WxAP Project has chosen three approaches to the technical challenges described previously and in figure 2. First is the development of weather products, displays, and decision support tools that are targeted at the needs of the flight crew and the cockpit environment. Embedded in this is the requirement that the flight crew, whether for commercial transport or general aviation aircraft, is often in a situation where decisions regarding flight path, et cetera, are made in collaboration with various air traffic management organizations.

One challenge in achieving these objectives is characterizing weather hazards as threats to aircraft. Different aircraft may not respond the same way to a particular atmospheric condition. Likewise, pilot experience and aircraft equipment may play a role in determining whether a particular atmospheric condition poses a threat. Finally, many atmospheric phenomena are poorly understood, or difficult to model, due to the complex nature of the physics involved. Developing sensor systems capable of measuring the required atmospheric phenomena and aircraft response is another technical challenge to achieving the stated objectives. In addition, presentation of weather information to the flight crew in an intuitive manner that will not increase workload is a challenge. This challenge requires an understanding of human response to graphical weather information introduced into the cockpit and the resulting decision processes. Finally, current communication architectures and datalinks are not economically feasible to support the dissemination of graphical weather images and atmospheric information between the ground and aircraft or between aircraft. Coverage and cost are big factors that affect implementation. Thus, the final challenge in achieving the stated objectives lies in the area of real-time datalink communication systems that are economically feasible.

To meet the challenge of characterizing weather-related threats, the WxAP Project is developing sensor systems that essentially turn an aircraft into an airborne weather data collector. Atmospheric data collection would occur without intervention of the flight crew and would be automatically downlinked to the appropriate forecast modelers and weather product developers. These data, including turbulence measurements during transport cruise as well as a variety of atmospheric variables collected at flight levels below 25,000 feet, will greatly increase the amount of in situ information currently available for the production and verification of weather forecast products.

The final challenge, that of disseminating weather information, will be met through the development of digital datalink technologies and architectures that will revolutionize aircraft-to-ground, ground-to-aircraft, and aircraft-to-aircraft information exchange. Similar to the development of decision aids, the development of datalink architectures and technologies must be performed with an awareness of the National Airspace System (NAS) communication infrastructure and related issues.

As previously discussed, the WxAP Project is organized into three elements focused on the following weather investments: AWIN, WINCOMM, and TPAWS. Each research element addresses one or more of the approaches described herein.

Scope

This document presents high level NASA Concepts of Operation for the Weather Accident Prevention (WxAP) Project.

WxAP Objectives and Approach

The overall objective is to improve flight safety by reducing the risks to flight associated with weather hazards. The intent of WxAP research and development activities is to cultivate a suite of enabling technologies that, when implemented into marketable products, meet or exceed the WxAP goal of: “developing enabling technologies to reduce weather-related accident casual factors by 25–50% and turbulence-related injuries by 25–50% by year 2007.” The vision of the WxAP Project is to assist in providing aviation users with accurate, relevant, and timely weather information in flight prior to encountering adverse weather conditions. WxAP has three primary objectives toward meeting its goal:

Objective Number 1: Develop technologies and methods providing pilots with sufficiently accurate, timely, and intuitive information during the en route phase of flight, which, if implemented, will enable a 25–50% reduction in aircraft accidents attributable to lack of weather situational awareness.

Objective Number 2: Develop communications technologies providing a three- to fivefold increase in datalink system capacity, throughput, and connectivity for disseminating strategic weather information between the flight deck and the ground and tactical turbulence hazard information between relevant aircraft. The technologies, if implemented along with other supporting technologies, will enable a 25–50% reduction in aircraft accidents attributable to lack of weather situational awareness and a 25–50% reduction in turbulence-related injuries.

Objective Number 3: Develop turbulence prediction technologies, hazard metric methods, and mitigation procedures to enable a 25–50% reduction in turbulence-related injuries.

WINCOMM Approach

WINCOMM develops, assesses, and recommends datalinks to provide accurate and timely dissemination of weather information—critical to the reduction of aircraft accidents—to and from the flight deck during the en route flight phase. It is expected that over the next 5 to 10 years the pilot will be able to make real-time decisions based upon this improved weather situational awareness.

As the system evolves, constrained en route airspace structures and boundary restrictions will no longer exist, requiring communications and computer systems that allow aircraft to no longer fly between navaids along static routes defined by the FAA. Datalink capabilities addressing limited bandwidth and coverage will be developed. These developments will allow this future vision/concept to provide the enhanced capability and required performance for graphical weather images in the en route service area. In addition, improvements to sensor technology and weather algorithms have placed additional demands on enhanced/improved air-to-ground as well as air-to-air datalink capabilities for both coverage and capacity. In order to meet these needs and requirements, development of advanced communication information technologies must occur that enable the efficient and timely dissemination of high quality, accurate aviation weather information to and from airborne users. The aviation weather communications system should address:

- National access and connectivity.
- Cross-segment operations, with emphasis on commercial transport and general aviation operators.
- Develop advanced communications systems, supported by network system modeling and in compliance with communications standards and protocols to enable the efficient implementation of advanced weather products.
- Information throughput, increasing the data rate for weather information between air and ground by a factor of 3 to 5 over current datalinks by the year 2007.
- Communications system capacity, increasing communication system capacity by a factor of 3 to 5 by the year 2007.
- User connectivity, improving user connectivity (ground-to-air, air-to-ground, and air-to-air) and coverage—50 feet above ground level (AGL) to 40,000 feet AGL—capabilities to all users by the year 2007.

AWIN Approach

The AWIN element will develop enabling technologies to provide accurate, timely, and intuitive information during the en route phases of flight to the flight deck, enabling the detection and avoidance of atmospheric hazards. New and derivative weather products will be developed, complementing existing weather sources with in situ and remote sensing capability where required, to provide necessary information at appropriate temporal and spatial resolution for both tactical and strategic decision making for aviation users. Enhanced weather presentations will be developed to minimize required interpretation and training, enhance situational awareness and engagement, and reduce workload. AWIN will also develop aids to improve decision making, including collaborative processes, and will identify training needs and guidelines to support use of weather information technologies in the cockpit. A combination of in-house research, contracted efforts, and collaborative teaming arrangements will be used to meet the AWIN element objectives.

TPAWS Approach

The TPAWS element will develop technologies and methods for providing flight crews with hazardous turbulence position information with a 90% level of confidence at least 2 minutes prior to encounter during the en route phase of flight. Achieving these objectives is expected to enable a 50% reduction in accidents attributable to a lack of turbulence situational awareness.

TPAWS will provide an advisory and warning of an impending hazardous turbulence ahead of the aircraft on the flight path. This warning will be in addition to advisory weather products datalinked from the ground-based weather stations/sources as well as the aircraft radar display. The pilot will rapidly comprehend potential impacts on the intended route of flight and take appropriate actions including securing the cabin.

TPAWS is intended to provide advisory and warning to the aircraft flight crew for en route detected turbulent weather. The basic system architecture involves the aircraft weather radar. The basic TPAWS capabilities will be added by software change to the radar of the aircraft. Advanced TPAWS interfaces involve communication datalinks between other aircraft flying in proximity and communication of turbulence data to ground-based weather stations using the existing datalinks onboard the aircraft. Future enhancements of TPAWS detection are:

1. The addition of Light Detection and Ranging (LIDAR). LIDAR technology components will enhance radar turbulence detection under clear air conditions.
2. Autopilot redesign for turbulence loads alleviation.
3. Wake vortex detection.
4. TPAWS function in all phases of flight.

For aircraft equipped with air-to-air and/or air-to-ground datalinks, TPAWS will provide turbulence weather information to other aircraft and to the ground weather stations. This will result in more accurate weather reports and forecasts and subsequently provide more efficient flight operations. Consistency of the TPAWS products will include use of color schema (magenta), symbology, hazard levels, and display format. Guidelines developed by NASA for the human-centered presentation of TPAWS information will be followed. Ground-based weather service providers will collect and assemble TPAWS

weather products from FAA approved weather sources, forecasts, and predictive weather models. The government and private providers will make basic TPAWS weather products available in much the same way other weather information is available today: Direct User Access Terminal System (DUATS), Flight Information Services Datalink (FISDL), Automated Surface Observing System (ASOS), and Flight Service Station (FSS).

Concept of Operations

The WxAP system is designed for use in the en route phase of flight. Weather information, including Next Generation Weather Radar (NEXRAD) data, is collected on the ground and processed for transmission via datalink to properly equipped aircraft. The information is received by the equipped aircraft and displayed in color as text and graphics in the cockpit. The system uses the latest technology datalink and cockpit graphical display systems to inform the pilot of the weather situation along his selected course. As the flight progresses, updated weather information is displayed in the cockpit for the pilot to use in collaborative decisions with appropriate ground entities (such as FSS) to continue on course or alter course for weather hazard avoidance. The WxAP system updates are displayed in the cockpit and provide recent (subject to data latency) datalink weather information. NEXRAD pictorial information and graphic aviation routine weather reports (METARs) are displayed in the cockpit. Decision support systems aid the pilot in identifying hazard areas for severe weather avoidance using the onboard displays and weather datalink updates. The current technology has a data latency factor, which limits the system to strategic decision use, due to ground sensor data processing time and transmission uplink time. As the technology evolves and improves, the data latency will reduce to levels where some information displayed can be used tactically. Commercial aircraft will have additional onboard sensors for real-time turbulence detection and warning, as well as other weather sensors. As the flight approaches the destination airport, onboard decision support systems will aid the pilot in transitioning to the approach phase of flight. Within the FAA NAS system, a pilot proceeding on an instrument flight rules (IFR) flight plan will additionally be informed by radio transmission from the ground of weather hazards at the destination airport. Methods by which information is received include tower, ATC, Airport Traffic Information System (ATIS), Hazardous In-flight Weather Advisory Service (HIWAS), ASOS, and Automated Weather Observing System (AWOS). Pilots proceeding on a visual flight rules (VFR) flight plan will be informed of weather changes and hazards by the onboard system and ground radio transmissions. The system will provide coverage for GA operations nationwide and transport operations worldwide. The system will inform the pilot of both the lateral and vertical extent of weather along the planned route of flight and alternate landing destination for the time of the flight. The system will provide weather observations and forecasts, and it will perform weather trending with comparison to the forecasted weather. The weather depiction could be presented on a map showing terrain and airspace in conjunction with airplane location.

WxAP Operational Concept

WxAP System Architecture

The WxAP system is intended to provide noncontrol advisory weather and flight information to aircraft pilots while en route. The basic system architecture involves both ground-based and airborne components that exchange information over one or more digital datalinks (fig. 3). Private companies and/or public sources own and operate the ground components and provide information to the aircraft operators, who equip their own aircraft. The ground-based components assemble weather information from a variety of approved sources, format the information for distribution, and manage the distribution network. Weather data include forecasts, current observations, and weather trend data. The airborne components create informational displays from data received from both ground and onboard systems and

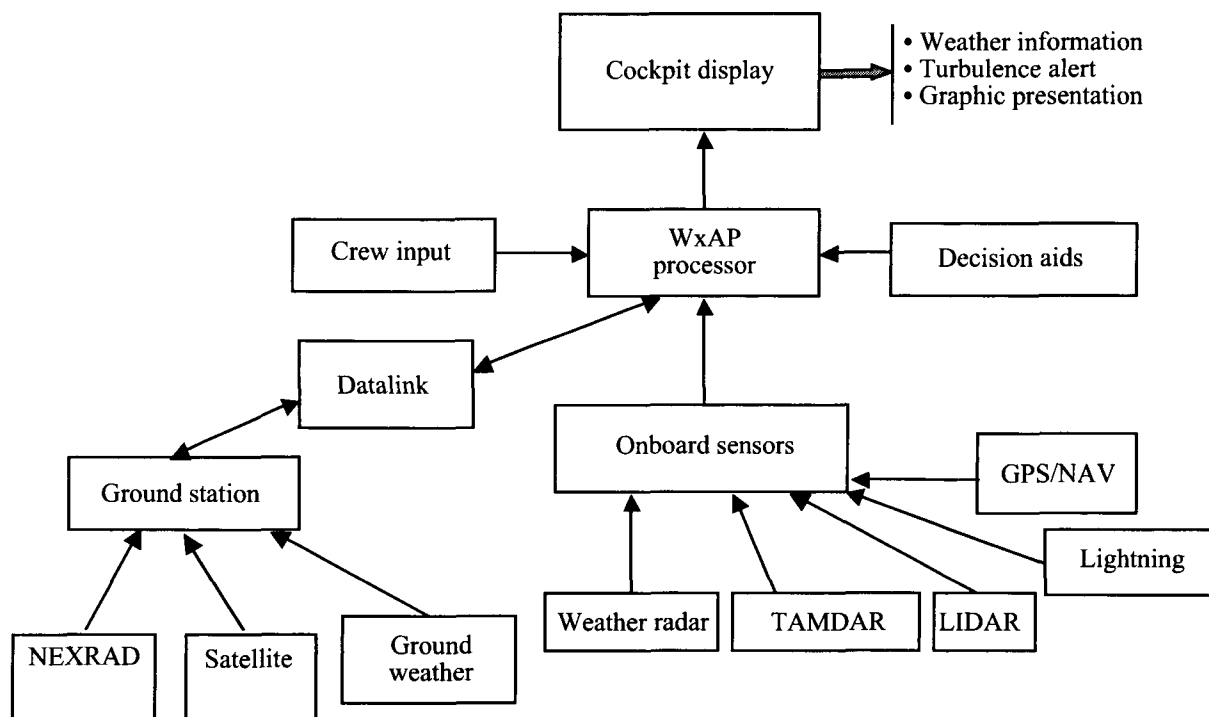


Figure 3. WxAP architecture.

manage the pilot interface. The datalinks deliver weather products and flight information to pilots at the appropriate times to facilitate use of the WxAP system for strategic planning and/or replanning of flight routes while airborne, all in a collaborative decision-making environment with ATC, and/or flight dispatch.

In addition to weather data, WxAP systems may evolve to use information on aircraft capabilities, operator capabilities, and data on flight path-relevant terrain, obstacles, airspace, and traffic (fig. 4) to provide advanced decision-aiding tools. Aircraft capabilities include such things as weight, performance, sensor complement, ice protection, gust alleviation, and vision enhancement. Operator capabilities include training, experience, currency, and human information-processing characteristics. Onboard databases will store terrain, obstacle, and airspace data for presentation on a Global Positioning System (GPS)-based moving map. Advanced implementations, on properly equipped aircraft, will also be capable of presenting near real-time air traffic data. Ultimately, the timeliness, accuracy, and presentation of weather information to the pilot must support decisions that result in safe and efficient actions.

WxAP solutions will be available and affordable for all classes of aircraft. For air carriers and business aviation aircraft, WxAP systems will provide weather information on a worldwide basis at normal jetway cruise altitudes. WxAP systems for general aviation aircraft will provide services throughout the continental U.S. for most cruise scenarios. For all classes of aircraft, technologies for both retrofit and fully integrated WxAP implementations will be developed.

Operational Environment

Operationally significant airspace can be defined for three distinct areas: the terminal area, the transition area or arrival/departure gate, and the en route or Air Route Traffic Control Center (ARTCC) area.

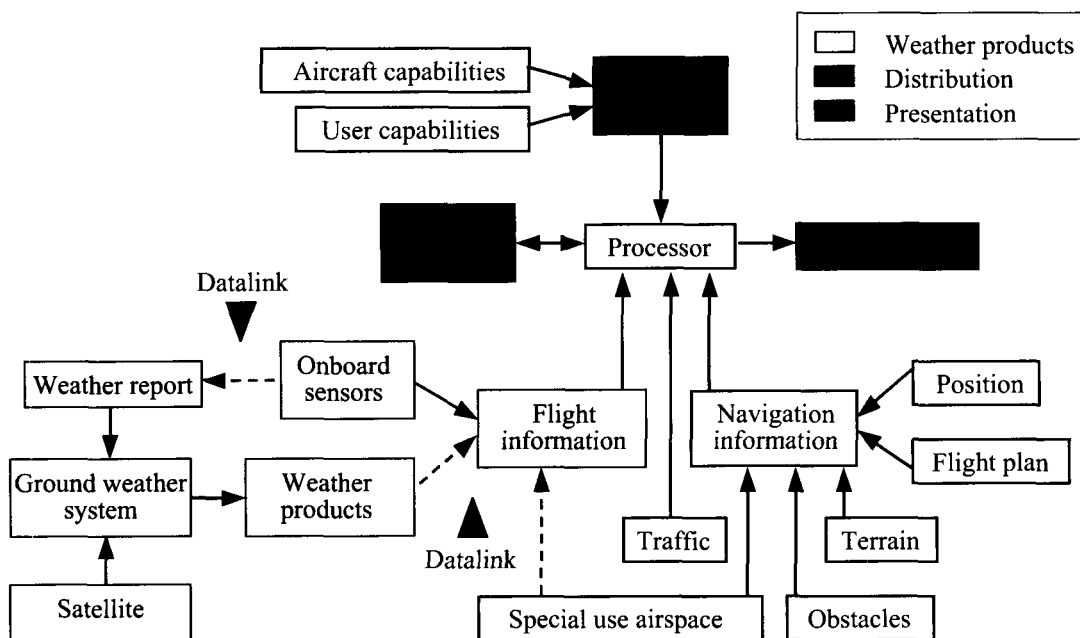


Figure 4. WxAP system concept.

The terminal area is defined here as the area within 20 nmi of the center of the runway complex. The arrival gate is defined as the airspace and routes existing from the top of the descent to the terminal area boundary including the approach gates (posts). The ARTCC area is defined as having predetermined traffic patterns within specified area boundaries that allow for the safe and efficient transit of air traffic through that airspace.

The terminal area is very important as controllers have limited airspace for maneuvering assigned aircraft. Further, the capacity of the terminal airspace is directly proportional to the proximity of impact weather to the operational runway(s). Because most weather-related accidents occur during the approach and departure phases of flight, defining the terminal area in this fashion ensures appropriate coverage of observed or forecasted weather in the immediate vicinity of the departure and arrival corridors. The associated ARTCC and approach control designate the arrival/departure gate, which can vary in size from terminal to terminal. Selection of appropriate gates allows aircraft to arrive ahead of or behind the weather. Knowledge of weather that may impact predetermined traffic patterns in the ARTCC area is crucial to managing traffic in the ARTCC, terminal, and arrival/departure gate areas.

Operationally significant time can initially be defined in terms of tactical or strategic importance (i.e., tactical is currently understood to mean up to 2 hours and strategic from 2 to 8 hours). Unfortunately, depending on the decision maker and where aviation-impacting weather is occurring, these quantifications can be too coarse for meaningful use if weather products are to be defined by them. Operationally significant time should be defined for 5 distinct periods: current, up to 5 minutes, up to 1 hour, from 1 to 2 hours, and from 2 to 8 hours.

Current observations of weather in the terminal, gate, or en route area are important for overall situational awareness and verification of predicted weather events. Weather expected within the next 5 minutes is needed for pilots and controllers in the terminal area to anticipate tactical changes of final approach or departure. Weather expected to occur within the next hour is required for short-term tactical planning, especially for Traffic Management (TM) decisions affecting terminal and gate areas, tower controllers, and en route controllers. For example, weather expected in a terminal area influences runway

and gate selection. If the tower controller changes the operational runway, movement of aircraft toward a particular arrival gate may change and TM personnel need to know whether the arrival gate associated with the new runway is available. This is necessary to allow coordination among appropriate air traffic entities and formulation and implementation of a plan.

Weather expected from 1 to 2 hours is important for long-term tactical planning because the majority of air transport flights within the U.S. have durations of less than 2 hours. TM and airline dispatch decisions rely on forecasts from 1 to 2 hours for final strategic and individual flight planning. Weather expected from 2 to 8 hours has a significant effect on airport capacity planning because maximum flight times for domestic travel fall within that timeline. Implementation of plans resulting from this information occurs as the onset of a weather event approaches. GA flights and other commercial operations may be of longer duration with slower en route speeds. These operations will rely on weather updates that affect the course flown and terminal airport conditions.

Collaborative Decision-Making Environment

Collaborative Decision-Making Conditions

Collaborative decision making (CDM) related to weather should occur within three environments: (1) between ground-side NAS operators for preoperational planning and operational planning purposes, (2) between pilots and weather service providers during preflight for preoperational planning purposes, and (3) between airborne pilots and weather service providers for en route operational planning purposes. The WxAP ConOps addresses the preflight and en route segments of these operations.

Preflight Pilot and Weather Service Provider CDM

During preflight planning, pilots collaborate with weather service providers, such as flight service specialists and airline operations specialists, to plan hazardous weather avoidance tactics for a proposed flight. This type of planning usually takes place over the telephone, or at the counter in the FSS, or at AOC. The effort usually results in a flight plan being filed.

En Route Pilot and Weather Service Provider CDM

Once en route, pilots collaborate with weather service providers by radio to update preflight weather information and to plan for hazardous weather avoidance tactics for conditions that have changed since the preflight weather briefing. FSS in-flight specialists and operations specialists provide weather updates and suggested reroutings, and Flight Watch (FW) specialists provide En-route Flight Advisory Service (EFAS).

WxAP systems will be advisory systems that promote more effective communications with AOCs, FSSs, and ATC by providing a shared view of the global weather situation. WxAP systems will provide weather products approved for aviation use but they will not replace current weather decision-making mechanisms. Rather, they will promote a collaborative decision-making environment in which pilots, controllers, and ground-based weather personnel have common weather information. This collaborative environment will result in safer, more efficient operations because all parties can actively participate in weather avoidance decisions. WxAP weather products, like graphical Significant Meteorological Information (SIGMET) and graphical special use airspace notices to airmen (NOTAM), will reduce cockpit workload and greatly reduce the possibility for misunderstandings. Pilots will no longer be required to construct a mental map of hazards based on bearings and distances from waypoints. The affected region

will be depicted graphically as a polygon on the AWIN base map display. Pilots will rapidly comprehend potential impacts on the intended route of flight, especially if the route of flight is also depicted on the AWIN display. Pilots will then be able to proactively contact an AOC, FSS, or ATC center well in advance of reaching the hazard. Similarly, ground controllers can expect pilots of AWIN-equipped aircraft to more rapidly assimilate flight route modifications and the reasons behind them.

User Classes and Modes of Operation

Categories of Users

There are three distinct categories of users for the WxAP systems: (1) air transport pilots, (2) commercial operations pilots, and (3) general aviation pilots. Within each category are operations involving different levels of onboard equipment and airplane types. The transport operations typically involve two pilots per airplane and fly above most weather systems. General aviation, commercial, and helicopter operations typically have one pilot and operate in the weather often below 25,000 feet.

System Operational Scenarios

Scenario Overview

The following scenarios illustrate WxAP system features in operational use to promote safety of flight and efficiency. The scenarios are typical operations that benefit from the WxAP system. They are divided into operations for transport category and general aviation aircraft because of the differences in equipage. Most transport aircraft have onboard weather radar and other sensors, while most general aviation aircraft do not. The WxAP system will provide information to aircraft via datalink to promote pilot improved situational awareness. The air transport pilots will use the WxAP systems in conjunction with onboard weather radar. As the technologies improve and the latency of weather information depictions from datalink sources is reduced, the pilot could use the information in conjunction with onboard sensors to make tactical decisions relative to weather. Commercial pilots flying aircraft that are not equipped with radar and other onboard sensors would exclusively use the information for flight planning and en route weather decisions of a strategic nature due to information latency. The system is not currently intended to be used as tactical information in locating thunderstorm cells and for penetrating storms, but it is useful in avoiding areas of bad weather. The general aviation pilot flying aircraft with minimal equipage will use the system for en route strategic course management to avoid bad weather.

Transport Aircraft

Convective weather #1. This scenario deals with encountering convective weather en route that requires a major replan of the flight path while operating in the current ATC system.

A transport aircraft operated under Federal Aviation Regulation (FAR) part 121 by a major airline with an AOC and an established route structure is scheduled for a midmorning flight. The flight crew obtains a standard preflight weather briefing from the AOC approximately 1 hour prior to the planned departure. The AOC advises that strong thunderstorms are expected to develop later in the day over the route of flight. AOC advises that the destination center expects traffic restrictions through the impacted area during the afternoon but there are no current SIGMETs or delays reported. Passengers are boarded, the flight crew activates the WxAP system as part of the predeparture checklist, and the aircraft departs on schedule. During the climb out, the WxAP system automatically retrieves new weather information that includes an updated convective forecast, updated turbulence forecast, new satellite image of cloud tops,

and current NEXRAD. The flight crew notes that weather conditions are deteriorating more rapidly than forecasted. En route the WxAP system automatically receives a new SIGMET that has just been issued for the weather-impacted region, new METARs and terminal area forecasts (TAFs) for airports along the route, new NEXRAD images, and satellite cloud data showing higher cloud tops than the previous image. The flight crew concludes that weather conditions are deteriorating fast enough to potentially impact the planned route. They query the onboard WxAP route optimization system for a new route that avoids the weather-impacted area. The route optimization system responds with a recommended route that is only slightly longer than the originally planned route. The flight crew calls the AOC, which has access to similar ground-based data to monitor trends, and requests the new route. The AOC concurs with the proposed new route and coordinates the rerouting with ATC. An amended clearance is issued from ATC and the flight completes the more northern route with no further assistance from the AOC. The flight is conducted more safely because there is an increased separation from potentially hazardous weather and there is minimal impact on the flight schedule. Because the flight does not enter the weather-impacted region, ATC vectors around significant weather, vectors for other traffic, potential holding patterns, and back tracks are avoided saving the airline about 5% on operating costs. The workload for ATC and AOC personnel is reduced because the flight avoids the most weather-impacted sectors and requires service from the AOC only once.

Convective weather #2. *This scenario deals with encountering convective weather en route that does not require a major replan of the flight path while operating in the current ATC system.*

A transport aircraft operated under FAR part 121 by a major airline with an AOC and an established route structure is scheduled for a late afternoon flight. A line of slow moving thunderstorms along the route has been causing some traffic delays. Most aircraft have climbed over the line of storms but they have encountered turbulence above FL300. The flight crew obtains a standard preflight weather briefing from the AOC approximately 1 hour prior to the planned departure. Potential exists for a weather impact on the flight but the reported tops are below the planned cruise altitude of FL310. The possibility of encountering moderate turbulence at the planned cruise altitude is the primary weather concern. Passengers are boarded and the flight crew activates the WxAP system during the predeparture checklist. The WxAP system automatically retrieves updated weather information during the climb out and continues to update the weather information as the flight progresses. The weather forecast is generally accurate; however, pilot reports of moderate turbulence in the area above FL300 continue and there are many requests for ride reports. The WxAP e-PIREP turbulence reporting system information confirms that aircraft above FL300 are experiencing turbulence. Consulting trend data for the NEXRAD uplink and satellite data, the flight crew determines that the storms are dissipating. The WxAP overlay of NEXRAD images with the aircraft's onboard radar allows the flight crew to look hundreds of miles in front of the aircraft for hazardous weather in addition to a real-time assessment of weather immediately ahead. The aircraft is equipped with turbulence prediction sensors scanning forward of the aircraft's flight path to detect hazardous atmospheric turbulence. The turbulence prediction system sensors are capable of detecting air turbulence from convective and nonconvective weather (which includes jet stream mountain-induced turbulence and other aircraft wake vortices). When the turbulence sensors detect air turbulence at hazardous levels of intensity up to 2 minutes ahead of the aircraft's flight path, a turbulence warning symbol appears on the radar or multi-function display (MFD) of the aircraft. The symbol depicts the turbulence location and size; simultaneously a turbulence aural warning is activated. The aural warning indicates that imminent severe turbulence will be encountered requiring the flight crew to take immediate action to reduce the aircraft speed to the maximum turbulent air penetration airspeed, set the autoflight system (on certain aircraft types) to turbulence mode, and warn the cabin flight crew of the impending turbulence hazard, who in turn secure the cabin. The flight crew reports the turbulence encounter to ATC. The flight crew requests from ATC a flight level and/or heading change. The flight

crew determines that they can safely descend to FL280, for turbulence avoidance, and use the ship's combined onboard weather radar and NEXRAD uplink data to monitor for hazardous weather. The onboard turbulence radar and AWIN hazard processor will assist the flight crew in detecting convective weather or turbulence ahead should any exist. The flight crew asks ARTCC for FL280 and is given clearance to descend. Only light turbulence is encountered as the flight completes the planned flight route without incident at the lower altitude. Safety is enhanced because potentially hazardous turbulence is avoided and there is no impact on the flight schedule. Passengers are pleased with the airline's ability to avoid an unpleasant, bumpy flight.

International operations. *This scenario deals with international flight operations in a developing part of the world where the ground-based infrastructure to support the collection and dissemination of en route weather information is minimal. The ATC environment is the future Free Flight system.*

A transport aircraft operated under FAR part 121 by a major airline on established international airways to South America is scheduled for a flight from Dallas-Fort Worth (KDFW), Texas, to Rio de Janeiro (SBGL), Brazil. Rapidly changing weather hazards exist along the route so the flight will be conducted under the new Free Flight rules to maximize routing flexibility. International flight operations are supported by a central AOC in the U.S. and regional field offices in South America, with much of the flight occurring over uninhabited territory. The flight crew obtains a preflight weather briefing from the AOC approximately 1 hour prior to the planned departure. AOC advises that towering convective storms with tops to 40,000 feet are forecasted over the Gulf of Mexico and northwest Brazil. Haze and possible mountain obscurities are expected in the SBGL vicinity at the estimated time of arrival (ETA). Columbia's Nevado del Ruiz volcano is actively spewing volcanic ash so there is an additional airborne hazard that must be avoided. AOC experts help to plan a safe and efficient route of flight using all available information, but it will be necessary to continuously monitor for changing weather conditions during the flight. Because the flight will be conducted off established airways and over sparsely populated regions, access to ground-based weather reports and flight service facilities will be limited due to minimal communications coverage in these areas.

The aircraft's WxAP system will provide a vital link to timely and accurate weather information. It will deliver convective and turbulence forecasts, actual satellite images of cloud tops, and automated control of the aircraft's onboard radar to help monitor the development of thunderstorms and maintain safe separations from cells. The aircraft is equipped with onboard predictive turbulence detection sensors scanning forward of the aircraft's flight path to detect hazardous atmospheric turbulence. The turbulence prediction system sensors are capable of detecting air turbulence from convective and nonconvective weather (which includes jet stream weather front, mountain-induced turbulence, and other aircraft wake vortices). When the turbulence sensors detect air turbulence at hazardous levels of intensity up to 2 minutes ahead of the aircraft's flight path, a turbulence-warning symbol would appear on the radar or MFD of the aircraft, which depicts the turbulence location and size. Simultaneously a turbulence aural warning is activated. The aural warning indicates that an imminent severe turbulence will be encountered requiring the flight crew to take immediate action to reduce aircraft speed to the maximum turbulent air penetration airspeed, set the autoflight system (on certain aircraft types) to turbulence mode, and warn the cabin flight crew of the impending turbulence hazard and to secure the cabin. The onboard e-PIREP turbulence reporting system and the flight crew reports the turbulence encounter to ATC. The flight crew requests from ATC a flight level and/or heading change. The clear air turbulence (CAT) forecast, the onboard turbulence prediction sensors, and the onboard e-PIREP turbulence system will help ensure a smooth ride for the passengers and safe operations for the aircraft. Weather conditions at SBGL and at other airports near the flight route will be automatically delivered to the flight. Data from new atmospheric measuring weather satellites will be distilled by centralized ground stations into weather products for the flight deck

that the aircraft's crew can use to determine measured winds, temperatures, and atmospheric conditions ahead of the flight. Ground-based weather information, including weather radar images, will be automatically sent to the aircraft whenever it becomes available. WxAP hazard processing algorithms will continuously scan all uplink weather information and report potential hazards to the flight crew. The WxAP route optimization system will be available to help replan the flight route while airborne, if necessary. All the weather information will be delivered through the WxAP system's hybrid ground/satellite communications link. The WxAP system will automatically switch to satellite-based communications over regions without ground links. In range of KDFW or SBGL, the system will automatically switch to high-speed ground-based communications networks that deliver near real-time weather and air traffic information directly from facilities at the airport.

The WxAP system has enhanced both weather and traffic situational awareness in the Free Flight environment. It has provided vital weather information in a remote region of the world where there is no ground-based infrastructure. Flight safety and passenger comfort have both been enhanced.

Transoceanic Operations. *This scenario deals with international flight operations over the ocean where the communications are limited to the High Frequency (HF) spectrum and the en route weather information collection and dissemination are minimal.*

A transport aircraft operated under FAR part 121 by a major airline on established international airways routes to Europe is scheduled for a flight from Kennedy (KJFK), New York, to London Gatwick (LGW), United Kingdom. The flight crew obtains a preflight weather briefing from the AOC approximately 1 hour prior to the planned departure. AOC advises that towering convective storms with tops to 40,000 feet are forecasted over the Atlantic and are shifting south at a rate and speed that might affect the ATC-assigned flight tracks. Because the flight will be conducted on an established airway and over the ocean, access to ground-based weather reports and flight service facilities will be limited. Transoceanic ATC clears the aircraft to cross the Atlantic at a specific flight track and altitude. The aircraft departs the North American coast and progresses across the Atlantic Ocean at an altitude and track specified by the transoceanic ATC. As the ground VHF Omni-directional radio Range (VOR) navigation signals fade, the aircraft continues navigating using its own inertial navigation system, INS/FMS-IRS (updated by GPS). The aircraft flies at the ATC-assigned specific altitude and track. All requests for altitude change are processed after the transoceanic ATC establishes a positive identification of the aircraft location either by Automatic Dependent Surveillance (ADS) or voice communication between the aircraft and ATC, or by positive indication on the ATC radar screen. North Atlantic flight operations are supported by four transoceanic operations centers (TOCs) located in the United States, Canada, United Kingdom, and Portugal. TOC experts help to plan a safe and efficient route of flight using all available information, but it will continuously monitor for changing weather conditions during the flight.

The aircraft's WxAP system will provide a vital link to timely and accurate weather information. It will deliver convective and turbulence forecasts, actual satellite images of cloud tops, and automated control of the aircraft's onboard radar to help monitor the development of thunderstorms and maintain safe separations from cells. The aircraft is equipped with onboard predictive turbulence detection sensors scanning forward of the aircraft flight path to detect hazardous atmospheric turbulence and e-PIREP turbulence reporting system. The turbulence prediction system sensors are capable of detecting air turbulence from convective and nonconvective weather (which includes jet stream weather front, mountain-induced turbulence, and other aircraft wake vortices). When the turbulence sensors detect air turbulence at hazardous levels of intensity up to 2 minutes ahead the aircraft's flight path, a turbulence-warning symbol appears on the radar or MFD of the aircraft, which depicts the turbulence location and

size. Simultaneously a turbulence aural warning is activated. The aural warning indicates that an imminent severe turbulence will be encountered requiring the flight crew to take immediate action to reduce the aircraft speed to the maximum turbulent air penetration airspeed, set the autoflight system (on certain aircraft types) to turbulence mode, steer the aircraft to the right 1 or 2 nmi of the assigned track to avoid or minimize the hazardous turbulence impact, and warn the cabin flight crew of the impending turbulence hazard so they can secure the cabin. The e-PIREP alerts ATC and the flight crew requests a flight level or track change from the transoceanic ATC. The CAT forecast and the onboard turbulence prediction sensors will help ensure a smooth ride for the passengers and safe operations for the aircraft. The WxAP route optimization system will be available to help replan the flight route while airborne, if necessary. En route weather conditions over the Atlantic and at other airports near the flight route will be automatically delivered to the flight crew. Data from new atmospheric measuring weather satellites will be distilled by centralized ground stations into weather products for the flight deck that the aircraft's crew can use to determine measured winds, temperatures, and atmospheric conditions ahead of the flight. WxAP hazard processing algorithms will continuously scan all the uplink weather information and report potential hazards to the flight crew. All the weather information will be delivered through the WxAP system's hybrid ground/satellite communications link. The WxAP system will automatically switch to satellite-based communications over regions without ground links. In range of the Ireland coast, the system will automatically switch to high-speed ground-based communications networks that deliver near real-time weather and air traffic information directly from facilities at the airport. No significant weather is encountered as the flight deviates around developing storms. The WxAP system has provided the pilot with weather information that allowed a proactive search for and avoidance of hazardous weather and, in case of developing convective weather, the onboard aircraft sensors provided a warning for impending hazardous turbulence.

General Aviation Aircraft

Convective weather avoidance. This scenario deals with avoiding potentially hazardous convective weather en route with a minor replan of the flight path while operating in the current ATC system.

A Lancair Columbia 300 operated under FAR part 91 by the aircraft's owner and pilot will be making a business trip. A nearly direct route along Victor airways is planned. An IFR flight plan is filed due to a forecast of extensive low clouds along the route of flight with widely scattered thunderstorms in the area. The airplane is well equipped for flight in instrument meteorological conditions (IMC) with a full panel of IFR avionics, a certified navigation GPS, an WxAP system, and an autopilot. The pilot is instrument rated and IFR current. A cruise altitude of 11,000 feet is planned, which will keep the aircraft above much of the weather. The pilot has contacted flight service for a standard weather briefing and monitored internet-based aviation weather during the morning. All reports are consistent with the initial forecast of extensive low clouds with widely scattered thunderstorms. There are no reports of any other hazardous weather along the route of flight except for a pilot report of moderate turbulence at 7,000 feet in the clouds over Elkins, West Virginia (KEKN). The pilot determines that the flight can be conducted safely using the WxAP system to monitor weather conditions ahead and taking advantage of the KEKN FSS located at the site of the PIREP. The airplane departs and immediately encounters low clouds but is able to climb above them into clear skies. En route the pilot notes cloud tops below the aircraft are at a much higher altitude and there appears to be extensive cloud development ahead. The pilot uses the WxAP system to examine the latest convective forecast, current NEXRAD images of precipitation along the route of flight, satellite images of cloud tops, and to check for any new PIREPS, SIGMETs, or Airman's Meteorological Information (AIRMET). There are no new reports, but the WxAP weather trend information clearly shows evidence of strengthening radar returns that correlate with the updated convective forecast. The pilot contacts the FSS and is advised that a localized region of storms is developing in the area.

It is likely that mature cells will exist in these storms by the expected time of arrival. The pilot elects to deviate around the storms and uses the WxAP route optimization feature to search for a new airway routing that will maintain a safe separation from the affected region. He proposes the deviation to ATC and is cleared for the new routing. No significant weather is encountered as the flight deviates around developing storms. The WxAP system has provided the pilot with weather information that allowed him to proactively search for and avoid hazardous weather. A potential inadvertent flight into an embedded thunderstorm has been avoided.

Nonconvective weather. *This scenario deals with nonconvective weather at the destination airport that requires an en route assessment of successfully completing the flight as planned. The ATC environment is the current NAS system.*

A business jet carrying a group of executives from Phoenix, Arizona (KIWA), to an early morning meeting in San Francisco is operated under FAR part 91 and equipped with a WxAP advisory system and a full suite of IFR instrumentation. It is not, however, certified for category II or category III approaches. A landing at San Francisco International (KSFO) is planned. As usual, a potential exists for morning fog in the San Francisco area and the fog density is difficult to predict. The flight crew has obtained a standard briefing from flight service and consulted a commercial weather provider. Both sources noted the potential for morning fog, but the preflight ceiling and visibility were above VFR minimums. Midway through the flight, the crew is alerted to changing conditions at KSFO when the graphical METAR on the AWIN display turns from green to yellow, indicating marginal VFR conditions now exist. A quick check of the text message reveals that a special report has just been issued for KSFO due to decreased visibilities and fog. The TAF for KSFO has also been amended to include fog and lower visibilities at the expected time of arrival. Datalink images of clouds in the KSFO area indicate the presence of low clouds, but cloud density is difficult to judge. Fortunately, the WxAP system provides the flight crew with access to highly accurate, short-term weather forecasts from the new KSFO ceiling and visibility system. The short-term forecast indicates category I conditions are expected at the time of arrival but not category II. The WxAP decision aid for mission evaluation indicates the probability of successfully completing the mission is greater than 90%. A decision is made to continue inbound to KSFO, monitor the short-term forecast, and query flight service for any additional information prior to descent. When another special report is issued and the KSFO graphical METAR turns red, the flight is already planning an instrument approach in low visibility conditions with the latest information from flight service. As part of the normal instrument approach procedures, the flight monitors the ATIS broadcast prior to executing a successful Instrument Landing System (ILS) approach. The WxAP system helped alert the flight crew to a potential hazard in time to effectively plan a course of action that achieved the mission objectives and enhanced safety. It provided weather information necessary to plan the course of action and helped objectively quantify the likelihood of success. The flight crew had improved weather situational awareness throughout the flight.

Icing avoidance. *This scenario deals with potential icing conditions at the destination and alternate airports that require an en route assessment of successfully completing the flight as planned. Congested airspace is also a factor. The ATC environment is the current NAS system.*

A Piper Arrow II operated under FAR part 91 by the aircraft's owner and pilot will be making a business trip. It is winter and a slow-moving cold front is pushing through the route of flight causing extensive low clouds and the threat of icing conditions. The flight will be conducted under IFR along Victor airways. The airplane is equipped for flight in IMC with a full panel of IFR avionics, a certified navigation GPS, an WxAP system, and an autopilot. The pilot is instrument rated and IFR current. However, the aircraft has no protection against ice, and icing conditions are the major weather concern. The pilot

has contacted the FSS for a standard weather briefing and monitored internet-based aviation weather during the morning. The forecasted freezing level is 6,000 feet in the area of the destination airport at the ETA. TAFs for the surrounding airports do not indicate any expected precipitation, but broken clouds below 2,000 feet AGL are expected at the ETA. An alternate airport is required and the pilot has chosen to look for a suitable substitute. The alternate airport has an acceptable forecast and it is only 25 nmi west of the destination. FAR 91.167 fuel requirements will be satisfied. The pilot concludes that the flight can be conducted safely using the WxAP system and weather updates from FSS to monitor for any reports of freezing conditions. The pilot makes a note on the flight plan to ask approach for the minimum en route IFR altitude (MEA) available through the class B airspace, enters the flight plan into the WxAP system, and lifts off into calm gray winter skies.

The WxAP system automatically updates weather products every few minutes and the flight proceeds uneventfully for the first 2 hours. The pilot monitors the WxAP icing forecast product for any changes and periodically checks current METARs at both the destination and alternate airports. The WxAP hazard processor alerts the pilot to a special report that has just arrived for the alternate airport. Weather conditions at the airport are still above alternate minimums, but freezing rain is now falling. The pilot decides to look for another suitable alternate airport and uses the AWIN graphical METAR to rapidly identify airports along the route of flight reporting VFR or marginal visual flight rules (MVFR) conditions. As a backup plan, the pilot also notes a heading that would lead to a large region where the NEXRAD display indicates no precipitation and airports are reporting VFR weather. To continue the flight as planned, the pilot must consider the current weather at the destination airport, the likelihood of encountering icing conditions, fuel requirements, the proximity to class B airspace, and the presence of heavy commercial air traffic. The WxAP system provides intuitive information in both graphical and textual form to assist with these decisions. The most recent icing forecast indicates no increased threat. Several airports along the route are now reporting VFR or MVFR conditions. NEXRAD trend information indicates that the precipitation is localized to the alternate airport region and not developing elsewhere. The extent of the class B airspace is clearly shown on the AWIN moving map with weather hazard and traffic overlays. Icing is still the only significant weather hazard near the class B airspace and there is no evidence of unusually congested air traffic. The pilot reverses his decision to avoid alternates in the class B airspace and selects a new alternate. It is very near the intended route of flight. The pilot contacts the FSS with specific weather questions and is able to efficiently amend the flight plan. The flight continues inbound and receives a clearance to descend to 3,000 feet from approach control. Underneath the broken clouds, the flight proceeds to a normal landing at the destination. The WxAP system has provided improved weather situational awareness throughout the flight, helped to identify when changes to the flight plan were necessary, and provided the information necessary for the pilot to make efficient and effective use of the NAS infrastructure.

Concluding Remarks

This Concept of Operations document provides the basis for the WxAP project to develop requirements based on the operational needs of the system users. It provides the scenarios that the flight crews, airline operations centers (AOCs), air traffic control (ATC), and flight service stations (FSS) utilize to reduce weather-related accidents. The provision to the flight crew of timely weather information provides awareness of weather situations that allows replanning to avoid weather hazards. The ability of the flight crew to locate and avoid weather hazards, such as turbulence and hail, contributes to safer flight practices. The facilitation of in-flight graphic weather updates to the pilots results in weather situation awareness, which in collaboration with AOCs, FSS, and ATC increases efficiency and safety.

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